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SPACELAB BASELINE ECS TRACE CONTAMINANT REMOVAL TEST PROGRAM

By C. D. Ray and J. B. Stanley
Structures and Propulsion Laboratory
and Test Laboratory

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16. ABSTRACT

"Off-the-shelf" components which have been demonstrated to offgas considerable quantities of trace contaminant gases will be flown as a part of Spacelab payload equipment. An estimate of the Spacelab Baseline Environmental Control System's contaminant removal capability was required to allow determination of the need for a supplemental trace contaminant removal system. Results from a test program to determine this removal capability are presented.

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I. INTRODUCTION

On past manned spacecraft programs, a combination of material selection control and system level testing was utilized to minimize material offgassing and the subsequent buildup of trace contaminants above safe levels. A similar approach will be used for the Spacelab subsystems, but an exception is planned for payload equipment [1] whereby scientific disciplines will fly off-the-shelf components. These components will not be required to meet NASA materials control requirements. Test results indicate that these components will outgas significant quantities of trace contaminants.

Analyses were conducted to determine if a supplemental trace contaminant removal system was required to control the expected contaminant generation rates. Input required to perform these analyses included an estimate of the contaminant generation rates and the Spacelab Baseline Environmental Control System (ECS) contaminant removal capability. A test program to obtain the baseline removal data was defined and performed at the Marshall Space Flight Center (MSFC). Results of this test program are presented.

II. BASELINE SPACELAB ECS DESCRIPTION

A schematic of the Spacelab Air Revitalization System (ARS) is shown in Figure 1. The ARS contains a cabin fan assembly, two lithium hydroxide (LiOH) canisters for CO_2 and odor removal, and a condensing heat exchanger (CHX) for removal of sensible heat and moisture. All these hardware items will be supplied by Hamilton Standard, Windsor Locks, Connecticut. The materials in the LiOH canister and the CHX have potential contaminant removal capability.

A pictorial view of the current design of the LiOH canister is shown in Figure 2. This radial flow bed contains 2.27 kg (5.0 lbm) of Navy Grade LiOH and a mixture of 68 gm (0.15 lbm) of Purafil[1] and 45 gm (0.10 lbm) of charcoal.

1. Purafil is the trade name of a material composed of activated alumina impregnated with potassium permanganate.

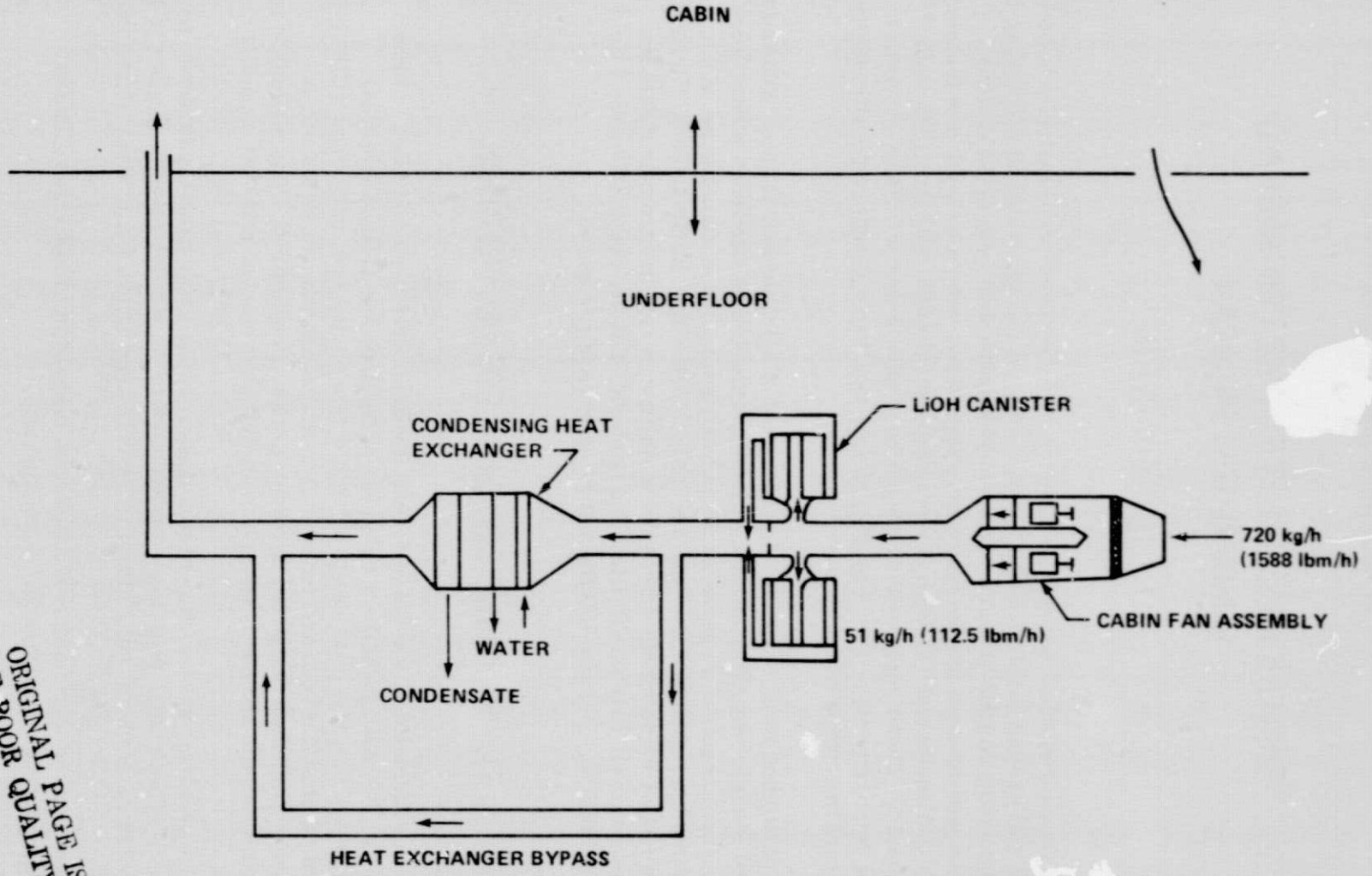

Figure 1. Spacelab air revitalization system.

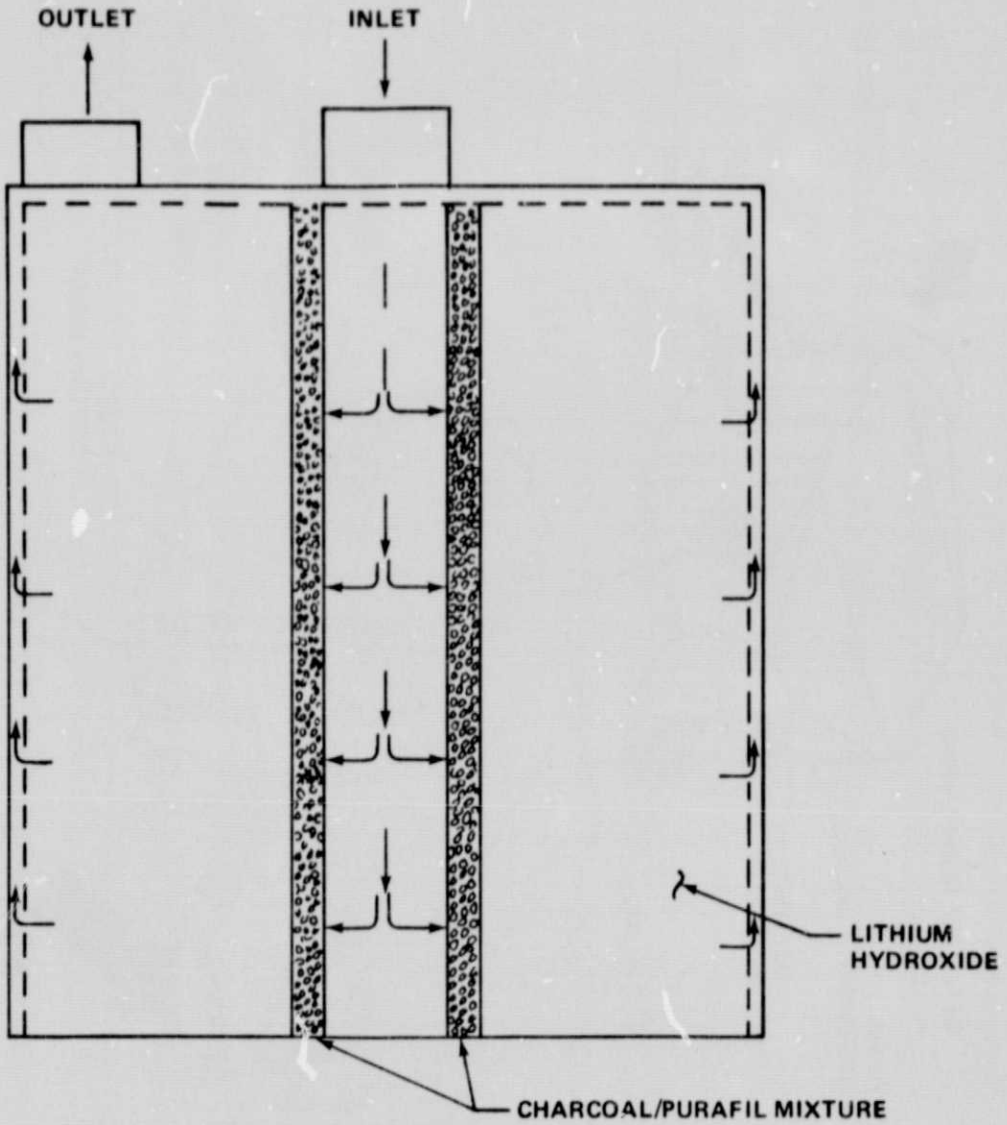

Figure 2. Lithium hydroxide canister.

Both LiOH canisters are on line during manned occupancy of Spacelab with a flow rate of 51 kg/h (26 cfm) through each. These flowrate data were obtained from Reference 2. A canister design change involving removal of the Purafil and an increase in the weight of charcoal and LiOH material is being studied, but details were not finalized at the time this report was written.

The CHX [3] is a multipass cross-counter flow plate — fin type having alternate layers of air and coolant fins separated by stainless steel parting sheets (Fig. 3). The heat exchanger core also contains a condensate removal device

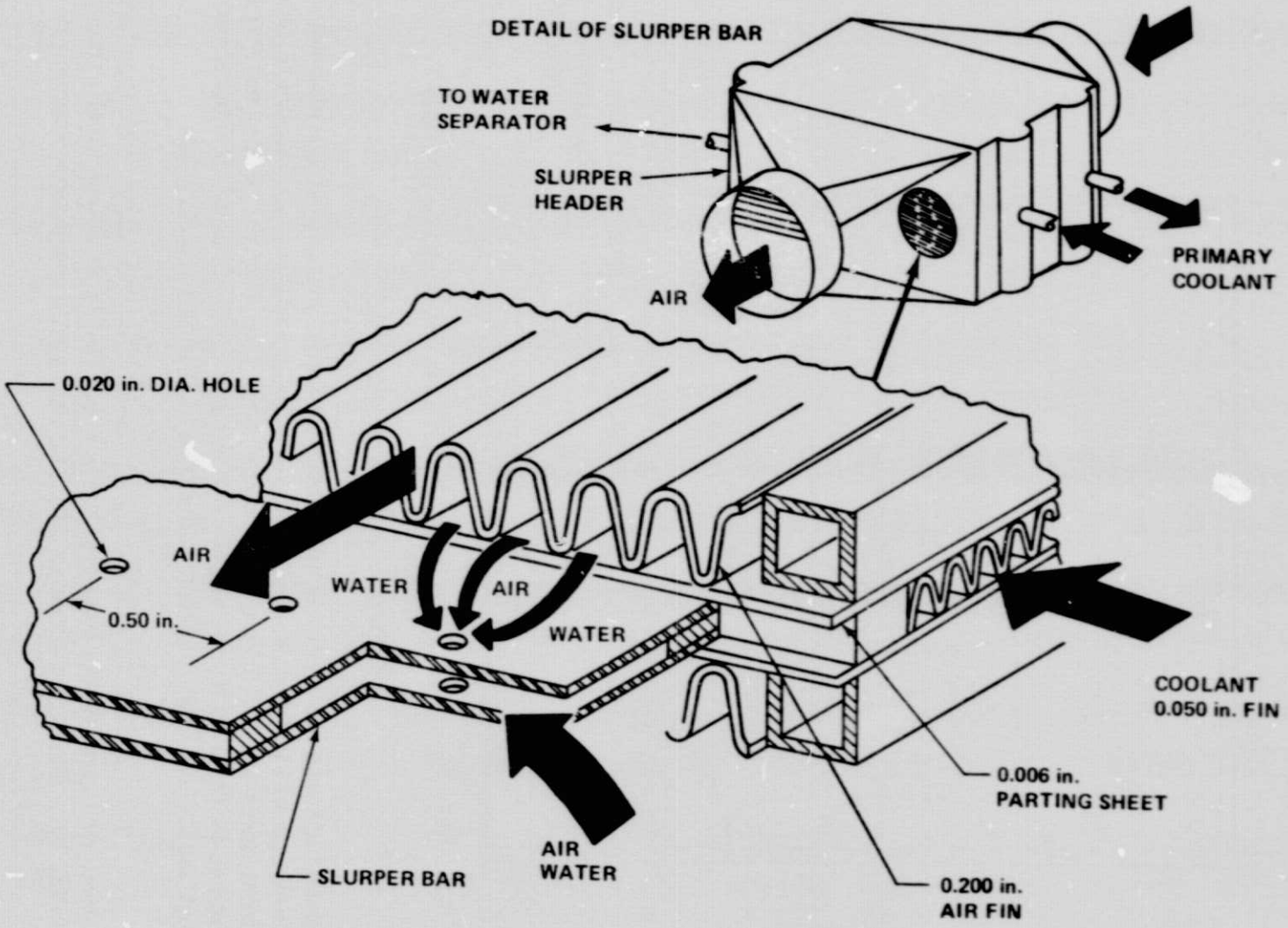

Figure 3. Spacelab condensing heat exchanger.

known as a "slurper." The slurper is located at the air outlet face of the core and transfers condensate water to a water separator for subsequent removal to a condensate storage tank. Flow through the CHX will vary depending on cabin heat load conditions. The maximum and minimum flow rates are 720 kg/h (1588 lbm/h) and 240 kg/h (529 lbm/h), respectively [2].

III. TEST PROGRAM DESCRIPTION

The test program was divided into three segments: Phase I, Phase II, and Phase III. Phase I testing consisted of individual tests of the contaminant removal capability of LiOH and Purafil material. The total system removal capability (LiOH canister plus CHX) was determined during Phase II and Phase III. For some contaminants during Phase II and III, the LiOH canister and CHX were tested on an individual basis.

A test matrix for Phase I is given in Table 1. Contaminants that were noted in Reference 4 as being removed by materials in the LiOH canister were tested. Because data were not available as to the expected spacecraft concentrations of each of these contaminants, each was tested at its maximum allowable concentration (MAC) level [5]. An arbitrary higher level was specified for those contaminants such as sulfur dioxide (MAC = 1 ppm) whose MAC level was too low to be measured by conventional analysis techniques. Charcoal testing was not included because sufficient removal data were available for this material.

Test matrices for Phase II and III are given in Tables 2 and 3, respectively. Each contaminant was tested at its MAC or at an arbitrary higher value similar to Phase I.

Hardware items for all three phases were assembled in a test chamber in Building 4476, Room 124. Tests were conducted by the Mechanical Simulations Branch of Test Laboratory and chemical analysis performed by the Analytical and Physical Chemistry Branch of Materials and Processes Laboratory.

TABLE 1. PHASE I TEST MATRIX

Test No.	Material	Weight kg (lbm)	Thickness cm (in.)	Contaminant	Level (ppm)
Phase I					
1	Purafil	0.113 (0.25)	0.51 (0.20)	Ammonia	25[a]
2	Purafil	0.113 (0.25)	0.51 (0.20)	Carbon Monoxide	15[a]
3	Purafil	1.13 (2.5)	1.27 (0.50)	Carbon Monoxide	15[a]
4	Purafil	2.5 (5.5)	2.54 (1.0)	Carbon Monoxide	15[a]
5	Purafil	0.113 (0.25)	0.51 (0.20)	N-Propyl Alcohol	5
6	LiOH	2.27 (5.0)	5.08 (2.0)	N-Propyl Alcohol	5
7	LiOH	2.27 (5.0)	5.08 (2.0)	Sulfur Dioxide	5
8	LiOH	2.27 (5.0)	5.08 (2.0)	Nitrogen Dioxide	5
9	LiOH	2.27 (5.0)	5.08 (2.0)	Ammonia	25[a]
10	LiOH	2.27 (5.0)	5.08 (2.0)	Carbon Monoxide	15[a]

a. Continuous allowable concentration level at 14.7 psia.

TABLE 2. PHASE II TEST MATRIX

Test No.	Contaminant	Chamber Level (ppm)
11	Methyl Alcohol	10[a]
12	Carbon Monoxide	15[a]
13	Methyl Chloride	10[a]
14	Toluene	50[a]
15	Benzene	5
16	Freon 113	500[a]
17	Isopropyl Alcohol	50[a]
18	Methyl Ethyl Ketone	20[a]
19	Freon 22	500[a]
20	Dichloromethane	25[a]

a. Maximum allowable concentration at 14.7 psia.

TABLE 3. PHASE III TEST MATRIX

Test No.	Contaminant	Test Configuration	Concentration (ppm)
21	Carbon Tetrachloride	LiOH + CHX	10
22	Chloroform	LiOH + CHX	10
23	Methyl Chloroform	CHX	10
24	Trichloroethylene	CHX	10
25	Allyl Alcohol	LiOH + CHX	2
26	1,1,2 Trichloroethane	LiOH + CHX	5
27	Acetone	1) LiOH 2) CHX	100[a]
28	1-Butanol	LiOH + CHX	10[a]

a. Maximum allowable level at 14.7 psia.

IV. PHASE I TEST PROGRAM[2]

A. Test Setup

The Phase I test setup (closed loop system) along with designation numbers for each test component is shown in Figure 4 and pictorially in Figure 5. Each of these designation numbers is identified in Table 4. The test hardware consisted of a prototype radial flow LiOH canister, compressor to supply flow through the bed, test chamber in which these two components were installed, grab sample ports, and hardware required to simulate and measure the required Spacelab environmental conditions given in Table 5.

Since flight hardware was not available, a prototype LiOH canister was developed by modifying a Hamilton-Standard Part Number SVSK 84404 Space Station Prototype Program canister. Modifications (Fig. 6) included addition of a wooden block in the bottom of the canister to give the proper depth of material as well as cylindrical wire screen spacers to give the desired material thickness. Navy Grade (MIL-L-20213D) LiOH and Purafil bulk replacement pellets were obtained to fill the canister for the various tests. The flowrate through the canister was 68.6 kg/h (35 cfm). This flowrate value was obtained from Reference 6.

Gaseous contaminants were inbled into the chamber from pressurized bottles while those in the liquid state were injected through a rubber diaphragm with a syringe. A small quantity of GN_2 was inbled to remove any liquid contaminant that might have been entrapped in the injection line.

Chamber dewpoint and drybulb temperatures were maintained through the operation of the CHX. CO_2 levels were maintained by an inbleed from a pressurized bottle of 100 percent CO_2.

B. Test Procedure

The test procedure was as follows:

1. Prior to each individual test, the contaminant inbleed conditions were established that would give the required initial chamber contaminant level. A trial injection technique was utilized whereby a known quantity of contaminant was injected into the chamber and a grab sample taken. This was repeated until the required contaminant quantity was determined.

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2. Information on the Phase I test setup and procedures were obtained from Reference 7.

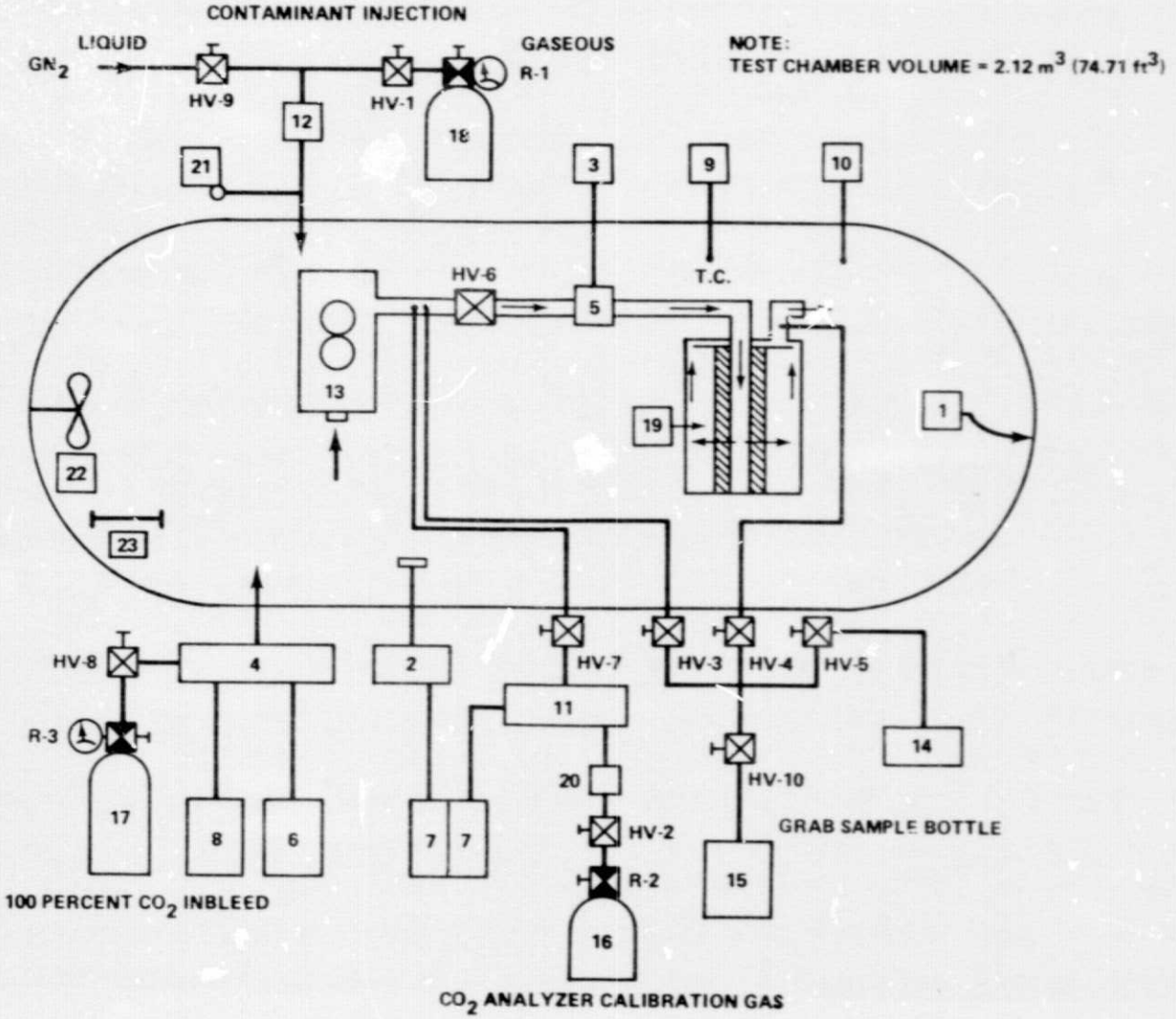

Figure 4. Phase I test setup.

Figure 5. View of Phase I test setup.

TABLE 4. PHASE I TEST HARDWARE LIST

Designation No.	Item
1	Test Chamber
2	Relative Humidity Indicator
3	Counter/Timer
4	CO_2 Mass Flow Transducer
5	Air Flow Meter
6	Digital Multimeter
7	2 Channel Strip Chart Recorder
8	Power Supply
9	Absolute Pressure Gage
10	Temperature Sensor
11	CO_2 Infrared Analyzer
12	Contaminant Flow Gage
13	Compressor
14	Vacuum Pump
15	Grab Sample Bottle
16	CO_2 Calibration Gas (2 percent CO_2, balance GN_2)
17	100 Percent CO_2 Gas
18	Gaseous Contaminant
19	LiOH Canister
20	CO_2 Calibration Gas Flow Gage
21	Liquid Contaminant Injection Port
22	Chamber Circulation Fan
23	Chamber Water Bath

TABLE 5. SPACELAB ENVIRONMENTAL CONDITIONS

Parameter	Value
Total Pressure	14.7 ± 0.2 psia
CO_2 Partial Pressure	0 - 5 mmHg maximum
Drybulb Temperature	65 to 80°F
Dewpoint Temperature	43 to 70°F

2. The prototype LiOH bed was then packed with the appropriate bed material. For tests using LiOH material, the bed was hand-packed by pouring in a small quantity, shaking, allowing the material to settle, then repeating the process until the bed was full.

3. Chamber environmental conditions as given in Table 5 were established. Chamber dewpoint and drybulb temperature were maintained through the use of a facility chamber heat exchanger. For the Purafil tests, the chamber CO_2 level was maintained at 5 mmHg. For the LiOH tests, CO_2 was inbled at a rate of 0.125 kg/h (0.275 lbm/h) and the chamber CO_2 partial pressure allowed to vary between 0 to 5 mmHg maximum depending on LiOH material CO_2 removal degradation. This inbleed rate is equivalent to the nominal CO_2 generation of three crewmen. When the CO_2 level reached 5 mmHg, the inbleed was decreased to maintain this level for the remainder of the test.

4. The compressor was turned off and the established quantity of contaminant injected into the test chamber.

5. The compressor was activated after sufficient time (5 min) had elapsed to allow for mixing of the contaminant and the chamber atmosphere.

6. Initial grab samples were then taken at the inlet and outlet of the prototype LiOH bed and analyzed. These initial grab samples were taken approximately 1 h after establishment of chamber conditions (Step 3). The analysis technique utilized depended on the contaminant tested; for example, CO was analyzed with gas chromatograph techniques, the ammonia with a specific ion electrode method, and sulfur dioxide with a spectrophotometer method.

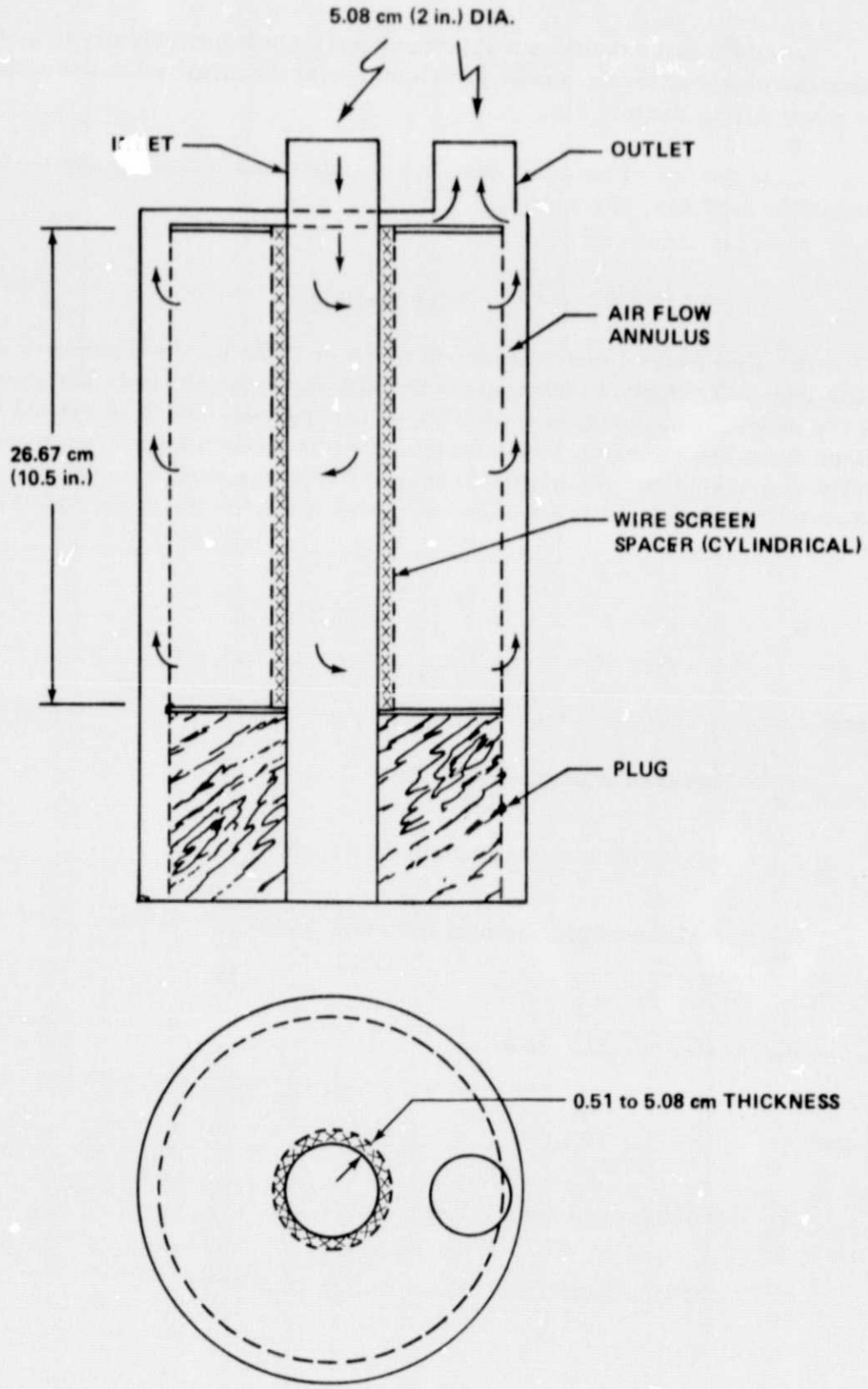

Figure 6. Canister configuration.

7. Additional contaminant injections were made periodically to maintain the desired chamber level. Other grab samples at the inlet and outlet of the bed were taken during the test day.

8. At the end of the work day, the chamber was locked up and the test resumed the next day, if required.

C. Test Results

Detailed Phase I test results are given in Table 6. Test numbers shown on this table correspond to those given in Table 1. In some cases the same test was run several times to give confidence in test results. Each individual test utilized fresh bed material. Test results given in Table 6 include grab sample results, calculated bed contaminant removal efficiency, and removal rates. Removal efficiencies and rates were calculated using the following equations:

$$N_R = \frac{C_i - C_o}{C_i} \qquad (1)$$

where

N_R = removal efficiency (percent)

C_i = inlet contaminant concentration (ppm)

C_o = outlet contaminant concentration (ppm)

$$R_R = (C_1 - C_2)(V_c)/\Delta t \qquad (2)$$

where

R_R = contaminant removal rate (mg/h)

C_1 = initial contaminant concentration (mg/m^3)

TABLE 6. PHASE I TEST RESULTS

Test No.	Material	Weight kg (lbm)	Thickness cm (in.)	Contaminant	Test Time (h)	Contaminant Injection	Sample Results (ppm)		Contaminant Removal	
							Test Chamber	Bed Outlet	Percent	mg/h
1	Purafil	0.113 (0.25)	0.51 (0.20)	Ammonia	0.33	2.5 psig for 5 s	2.8	1.6	42.8	
					4.25	2.5 psig for 5 s	71.8	44.3	38.6	**
					0.33	2.5 psig for 5 s	8.7	6.4	26.5	
					3.66	—	4.3	3.4	21.0	1.63
					0.25	2.5 psig for 30 s	16	5.9	63	
					3.75	—	4.3	5.4	0	4.84
2	Purafil	0.113 (0.25)	0.51 (0.20)	Carbon Monoxide	0.33	1350 cc min for 30 s	12.2	10.1	0	***
					3	—	10.7	10.6	0	1.38
3	Purafil	1.13 (2.5)	1.27 (0.50)	Carbon Monoxide	0.5	1350 cc min for 30 s	21.1	23.0	0	
					4.33	—	24	21	0	**
4	Purafil	2.5 (5.5)	2.54 (1.0)	Carbon Monoxide	0.75	1350 cc min for 30 s	20.7	20.7	0	***
					4.25	—	18.7	18.7	0	1.41
5	Purafil	0.113 (0.25)	0.51 (0.20)	N-Propyl Alcohol	0.66	0.2 cc	13	8	38.5	
					3	—	0.97	0.4	58.8	24
					*					
					4.66	0.1 cc	3.9	1.4	64.1	
					6.75	—	0	0	—	
					0.25	0.1 cc	0.3	0.3	0	
					2.0	0.05 cc	2.58	0.83	68	
					4.0	0.05 cc	4.58	2.6	43.2	**
6	Loam	2.27 (5.0)	5.08 (2.0)	N-Propyl Alcohol	0	0.2 cc	4.7	1.8	61.7	
					2	—	0.2	0.08	60.0	11.69
					*					
					6	0.2 cc	1.66	1.62	2.4	
					8	0.15 cc	4.5	3.5	22.2	**

*Overnight Lockup
**No Calculation Possible
***Questionable Data (See Phase II test results and text, page 17.)

TABLE 6. (Concluded)

Test No.	Material	Weight kg (lbm)	Thickness cm (in.)	Contaminant	Test Time (h)	Contaminant Injection	Sample Results (ppm)		Contaminant Removal	
							Test Chamber	Bed Outlet	Percent	mg/h
7	LiOH	2.27 (5.0)	5.08 (2.0)	Sulfur Dioxide	0.5	100 cc/min for 5 s	5.7	0.1	100	
					4	160 cc/min for 5 s	4.5	0.8	82	
					6.5	—	0.8	No Sample	—	8.15
8	LiOH	2.27 (5.0)	5.08 (2.0)	Nitrogen Dioxide	0.75	1350 cc/min for 15 min	1	No Sample	—	
					3	—	No Sample	0	—	**
					4	2500 cc/min for 20 min	1.1	No Sample	—	
					6.5	—	No Sample	0	—	**
					7.5	2500 cc/min for 20 min	1.8	No Sample	—	
					9.5	—	No Sample	<0.1	—	**
9	LiOH	2.27 (5.0)	5.08 (2.0)	Ammonia	2	2.5 psig for 45 sec	302	174	42.4	
					5	—	53.8	No Sample	—	119.26
					6	2.5 psig for 15 s	29.3	25.6	12.6	
					9.5	—	18.9	4.7	75.0	4.28
					2	2575 cc/min for 45 s	169	27.4	83.8	
					5.5	—	27.1	11.5	57.6	60.92
					6	—	13.8	15.0	0	
					9.75	—	12.8	7.7	40	
10	LiOH	2.27 (5.0)	5.08 (2.0)	Carbon Monoxide	2	1350 cc/min for 20 s	—	—	—	
					2.5	—	20.9	20.9	0	0

C_2 = final contaminant concentration (mg/m^3)

V_c = test chamber volume (m^3)

Δt = test time (h) .

Several difficulties were encountered during Phase I testing and are reflected in the data given in Table 6. These difficulties were:

1. It was impossible to maintain a constant chamber concentration with the closed loop test configuration when a material being tested was a strong contaminant removal agent. It was initially planned to periodically inject contaminant into the test chamber to maintain a constant concentration but the lag time associated with obtaining grab sample results made this technique unworkable. It is believed that the variation of removal efficiencies and rates from test to test (Table 6) was due to the fact that the chamber concentration was not held constant.

2. In some cases it was impossible to make removal rate calculations due to the fact that attempts were made to maintain the chamber concentration level at a constant value.

3. The length of time required (approximately 6 h) to analyze nitrogen dioxide grab samples (test No. 8) make it impossible to obtain adequate sample results.

Test results indicate that Purafil removes N-propyl alcohol, and ammonia. Test results indicates that Purafil removed carbon monoxide to a limited degree, but these data are doubtful because later Phase II test results did not indicate removal of carbon monoxide by Purafil material.

The LiOH material removed ammonia, N-propyl alcohol, nitrogen dioxide, and sulfur dioxide, but not carbon monoxide. It is theorized that the ammonia and N-propyl alcohol were removed by dissolving in the water produced by the $LiOH/CO_2$ reaction.

V. PHASE II TEST PROGRAM[3]

A. Test Setup

The Phase II test setup, along with designation numbers for each test component, is shown in Figure 7 and pictorially in Figure 8. Each of these designation numbers is identified in Table 7. The test hardware consisted of the same prototype radial flow LiOH canister as was used during Phase I testing, sensible/CHX, compressors to supply flow through the canister and heat exchanger, test chamber in which these components were installed, grab sample ports, and hardware required to simulate and measure the required Spacelab environmental conditions (Table 5).

The prototype LiOH canister from Phase I testing with cylindrical wire screen spacers separating the charcoal/Purafil mixture and LiOH material were used to simulate the flight hardware item. Sixty-eight grams (0.15 lbm) of Purafil and 45 gm (0.10 lbm) of Barnebey Cheney 6 × 8 mesh type EH activated charcoal were mixed together and separated with a wire screen from the 2.27 kg (5.0 lbm) of Navy Grade LiOH material. A Hamilton Standard Part Number SVSK 88394 Space Station Prototype Program tube-fin design sensible/CHX and water separator were used to simulate the flight heat exchanger. A complete description of these hardware items is given in Reference 8. Water at a flowrate of 227 kg/h (500 lbm/h) and an inlet temperature of 2 to 7.2°C (35 to 45°F) was utilized as a coolant for the heat exchanger. Flowrates for the LiOH canister and heat exchanger were 68.6 kg/h (35 cfm) and 459 kg/h (225 cfm), respectively.

Contaminant and CO_2 levels were maintained in the same manner as during Phase I. Chamber dewpoint and drybulb temperature were controlled by a combination of the chamber and test CHX.

B. Test Procedure

Before testing, the charcoal was purified according to the following procedure:

1. The charcoal was placed in a vacuum chamber at ambient pressure and heat was applied for 10.5 h. The chamber temperature had increased to 99°C (210°F) at the end of 10.5 h. The chamber was shut down and then turned on the next day for 12 h. The chamber temperature had increased to 112.2°C (234°F) and was maintained for 22.5 h.

3. Information on the Phase II test setup and procedures were obtained for Reference 7.

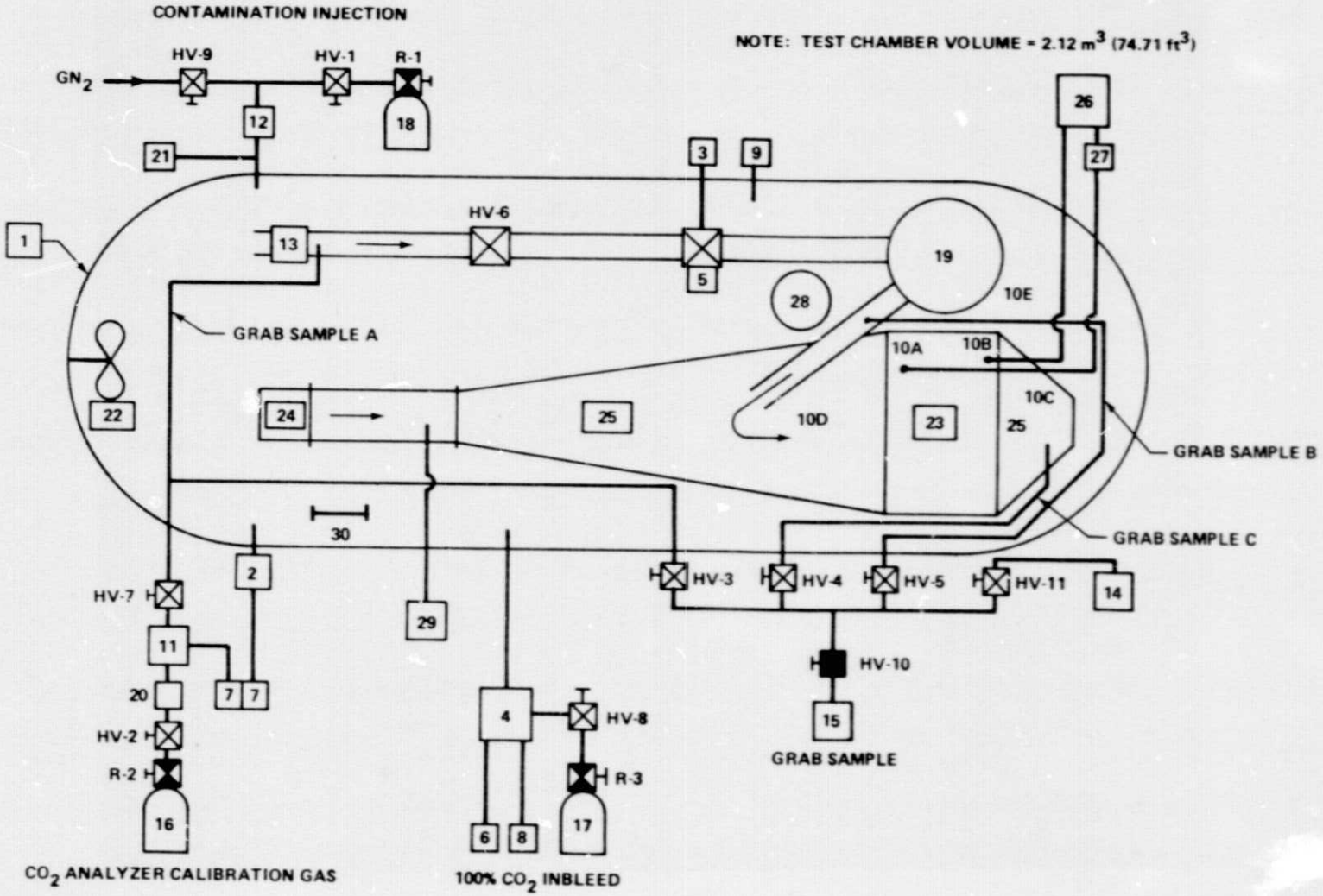

Figure 7. Phase II test setup.

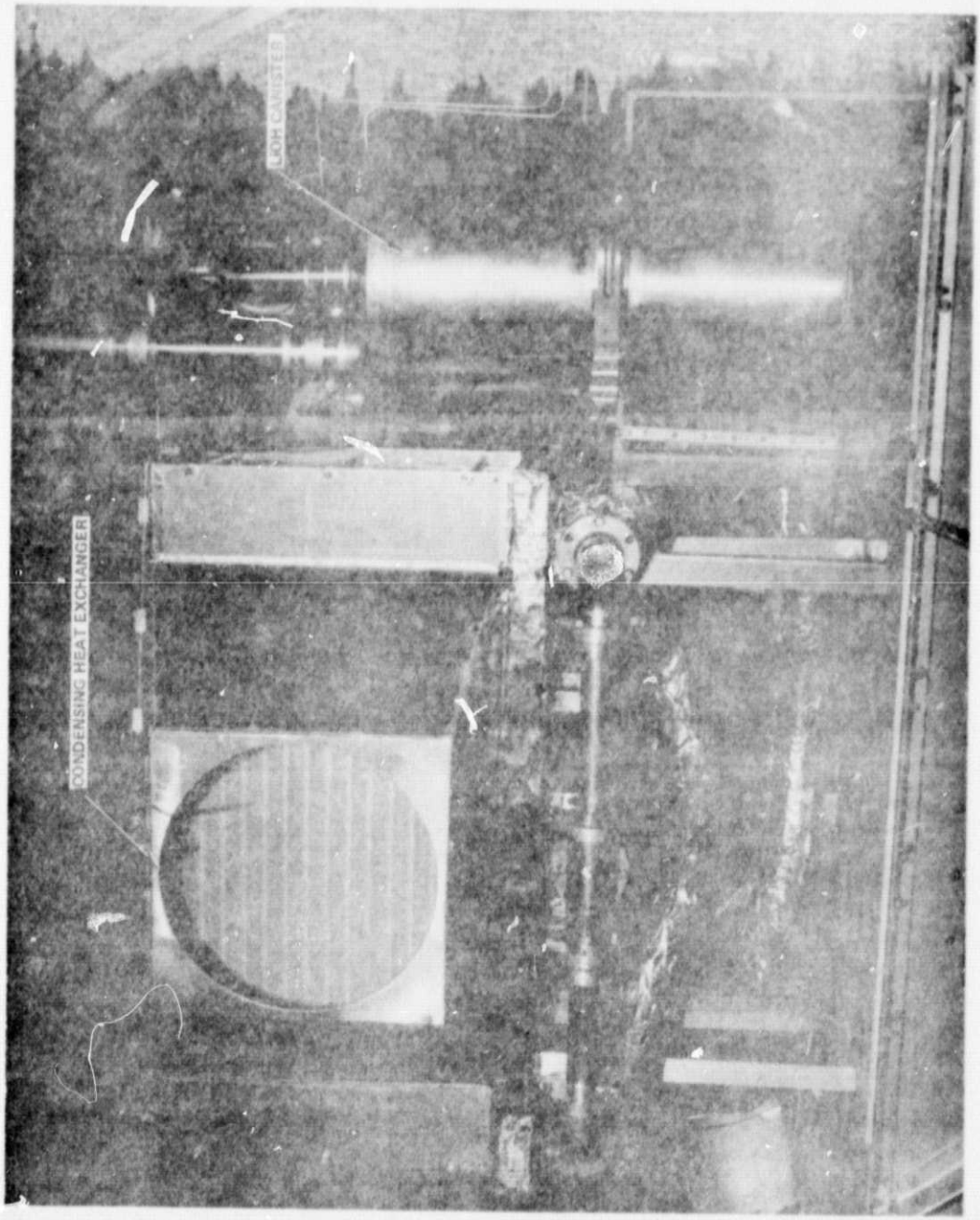

Figure 8. View of Phase II test setup.

TABLE 7. PHASE II HARDWARE LIST

1. Test Chamber
2. Relative Humidity Measurement System
3. Counter/Timer (Flowrate)
4. Linurmass Meter
5. Flow Meter
6. Digital Meter
7. Strip Chart Recorder (2 Channel)
8. Power Supply
9. Pressure Gage (Absolute)
10. Temperature Sensors (T/C)
    - A. Inlet CHX H_2O Temperature
    - B. Outlet CHX H_2O Temperature
    - C. Outlet CHX Air Temperature
    - D. Inlet CHX Air Temperature
    - E. Chamber Bulk Air Temperature
11. CO_2 Analyzer
12. Flow Gage
13. Compressor
14. Vacuum Pump
15. Gas Sample (Grab Bottle)
16. CO_2 Gas (Calibration)
17. CO_2 Gas (100 percent)
18. Contaminant
19. LiOH Canister
20. Flow Gage
21. Liquid Injection Port (Contaminant)
22. Chamber Circulation Fan
23. Condensing Heat Exchanger
24. Compressor
25. Plenum
26. Water Chiller
27. Flow Meter
28. Water Separator
29. Air Velocity Meter
30. Chamber Water Bath

2. The charcoal was then heated at a chamber pressure of 8 μ for 31 h. The chamber temperature was 141°C (286°F) at the end of 31 h.

3. The chamber heat was deactivated, but the 8 μ pressure was maintained for an additional 9 h.

The test procedure followed during Phase II testing was:

1. Prior to each test, the contaminant inbleed conditions were established that would give the required initial chamber contaminant level. As during Phase I testing, a trial injection technique was used (Section IV.B.).

2. The prototype LiOH bed was then packed as described in Section IV.B and installed in the chamber.

3. Chamber environmental conditions as given in Table 5 were established. Dewpoint and drybulb temperature were maintained through the use of both the chamber and test heat exchangers. CO_2 was inbled at a rate of 0.125 kg/h (0.275 lbm/h) and the chamber CO_2 partial pressure allowed to vary between 0 to 5 mmHg maximum. When the CO_2 level reached 5 mmHg, the inbleed was decreased to maintain this level for the remainder of the test. Instrumentation was monitored periodically to ensure that chamber conditions were maintained.

4. The compressors were turned off and the established quantity of contaminant injected into the test chamber.

5. The compressor was then activated after sufficient time (5 min) had elapsed to allow for mixing of the contaminant and the chamber atmosphere.

6. Grab samples were then taken at the inlet to the LiOH canister (Sample A), outlet from LiOH canister (Sample B), and outlet from the CHX (Sample C). For some tests, only inlet LiOH canister samples (chamber level) were taken. Additional grab samples were taken during the test. The chamber contaminant level was allowed to drift, with no attempt made to maintain a constant chamber level.

7. At the end of the work day, the chamber door was opened and left open overnight so that the chamber air would clear of contaminant. The next day, contaminant was injected to re-establish the required level.

C. Test Results

Detailed Phase II test results including grab sample results, calculated contaminant removal efficiency, and rates (using the equations in Section IV.C) are given in Table 8. Grab samples were taken at the inlet to the LiOH canister (chamber level), outlet of the LiOH canister, and the outlet of the CHX. The CHX inlet concentration was calculated using the following equation:

$$X = \frac{(\text{Sample A Level})\ (\dot{Q}_1) + (\text{Sample B Level})\ (\dot{Q}_2)}{\dot{Q}_T} \qquad (3)$$

where

Sample A Level = ppm

$\dot{Q}_1$ = main compressor flowrate

Sample B Level = ppm

$\dot{Q}_2$ = LiOH canister flowrate

$Q_T = \dot{Q}_1 + \dot{Q}_2$.

All of these tests were run at an LiOH canister flowrate of 68.8 kg/h (35 cfm). Data obtained near the end of Phase II testing indicated that the LiOH canister flowrate will actually be 51 kg/h (26 cfm). The test flowrate is sufficiently close to the actual design flowrate to allow the test data to be utilized to determine baseline contaminant removal capability.

Test results indicated that the Spacelab baseline ECS will remove methyl alcohol, Freon 113, isopropyl alcohol, methyl ethyl ketone, and dichloromethane. No removal was noted for carbon monoxide or methyl chloride. Inconsistent data were obtained for the tests of toluene and benzene (tests 14 and 15). For both contaminants heat exchanger removal was noted for the combined CHX/LiOH canister test yet no heat exchanger removal was shown when the CHX was tested alone. Empirical data indicate that the CHX will not remove either of these contaminants; therefore, it is believed that the CHX/LiOH canister test data are in error. The test data for Freon 22 were obtained at test chamber concentrations well above its MAC (MAC = 100 ppm, test chamber concentrations between 310 and 382 ppm), and, therefore, it is not representative of spacecraft conditions.

TABLE 8. PHASE II TEST RESULTS

Test No.	Contaminant and Test Configuration	Test Time (h)	Contaminant Injection	Sample Results (ppm) A Inlet LiOH	B Outlet LiOH	Inlet CHX†	C Outlet CHX	Contaminant Removal LiOH (%)	CHX (%)	mg/h
11	Methyl Alcohol — LiOH - CHX	1.33	0.1 cc	5.7	2.0	5.1	2.7	65	47	
		5.5	—	0	0	0	0	—	—	
		7.0	—	—	—	—	—	—	—	**
		↕ *								
		8.983	0.1 cc	15.3	4.0	13.5	2.5	74	92	
		12.25	—	0	0	0	0	—	—	
		14.25	—	—	—	—	—	—	—	**
11	Methyl Alcohol — CHX	0.5	0.1 cc	13.0	—	—	6.6	—	49	
		1.5	—	0.9	—	—	0.9	—	—	33.35
		4.5	—	< 0.5	—	—	< 0.5	—	—	
		6	Open Chamber Doors	—	—	—	—	—	—	
		0.25	0.2 cc	29.1	—	—	17.0	—	41	
		1.25	—	3.7	—	—	3.2	—	13.5	
		2.25	—	1.7	—	—	1.8	—	—	37.76
		5.75	—	—	—	—	—	—	—	
12	Carbon Monoxide LiOH - CHX	1	675 cc	9.4	9.0	9.33	8.9	0	0	
		5	—	11.4	11.3	11.4	11.7	0	0	0
		8	Open Chamber Doors	—	—	—	—	—	—	
		↕ 3 Days								
		9	675 cc	11.9	11.8	11.88	11.1	0	0	
		13	—	10.7	10.6	10.68	10.6	0	0	0
		16	Open Chamber Doors	—	—	—	—	—	—	
13	Methyl Chloride LiOH - CHX	1	200 cc min for 5 s	5.8	5.5	5.75	5.8	0	0	
		5	—	6.9	6.9	6.9	6.7	0	0	0
		8	Open Chamber Door	—	—	—	—	—	—	
		↕ *								
		9	200 cc min for 5 s	9.8	9.9	9.81	9.9	0	0	
		13	—	10.9	10.9	10.9	10.9	0	0	0
		16	Open Chamber Doors							

* Overnight Lockup
** Calculation Not Possible
† Calculated Value

TABLE 8. (Continued)

Test No.	Contaminant and Test Configuration	Test Time (h)	Contaminant Injection	Sample Results (ppm)				Contaminant Removal		
				A Inlet LiOH	B Outlet LiOH	Inlet CHX†	C Outlet CHX	LiOH (%)	CHX (%)	mg/h
14	Toluene — LiOH - CHX	2	0.5 cc	40.5	26.6	38.3	22.5	34.3	41.2	
		6	—	0.1	0.1	0.1	0.1	0.0	0.0	**
		8	—	—	—	—	—	—	—	
		‡ *								
		10	0.5 cc	44.7	29.1	43.3	23	35	46.8	
		14	—	0.5	0.4	0.5	0.5	0	0	**
		16	—	—	—	—	—	—	—	
14	Toluene — CHX	1	0.5 cc	30.1	—	—	49.7	—	0	
		3	—	39.6	—	—	39.3	—	≤0	
		6	—	25.8	—	—	32.3	—	0	**
		7.5	—	—	—	—	—	—	—	
		‡ *								
		8.5	0.5 cc	49.6	—	—	53.5	—	0	
		10.5	—	30.6	—	—	41.4	—	0	
		13.5	—	36.6	—	—	34.2	—		**
15	Benzene — LiOH - CHX	2	0.05 cc	6.8	4.9	6.7	4.1	28	38	
		4	—	0.1	0.1	0.1	0.1	0	0	**
		8	—	—	—	—	—	—	—	
		‡ *								
		9	0.5 cc	7.2	5.0	7.0	3.7	30	47.2	
		10	—	0.4	0.4	0.4	0.4	0	0	**
15	Benzene — CHX	1	0.2 cc	36.3	—	—	34.8	—	4.1	
		2	—	29.1	—	—	31.6	—	0	
		3	—	30.4	—	—	30.2	—	0	
		6	—	28.2	—	—	27.1	—	0	10.3
		7	—	—	—	—	—	—	—	
16	Freon 113 — LiOH - CHX	1	5 cc	417	337	405	333	19	18	
		5	—	92.6	84.5	91.3	86.8	9	5	**
		7.5	—	—	—	—	—	—	—	
		‡ *								
		8	5 cc	531.1	429.7	515	448.5	19.4	13	
		13	—	418.2	426.3	419.5	424.6	0	0	366.69
		15	—	—	—	—	—	—	—	

TABLE 8. (Concluded)

Test No.	Contaminant and Test Configuration	Test Time (h)	Contaminant Injection	Sample Results (ppm) A Inlet LiOH	B Outlet LiOH	Inlet CHX†	C Outlet CHX	Contaminant Removal LiOH (%)	CHX (%)	mg/h
17	Isopropyl Alcohol — LiOH + CHX	1	0.8 cc	39.3	14.1	35.4	17.5	64	50.6	
		3	—	2.8	< 2.5	2.75	3.3	0	0	
		5	—	5.2	5.6	5.26	6.0	0	0	47.3
		5.5	—	—	—	—	—	—	—	
		‡ *								
		6.5	0.8 cc	28.1	10.4	25.3	15.9	63	37.3	
		8.5	—	6.2	6.1	6.18	6.2	1.6	0	
		10.5	—	4.1	3.7	4.04	3.9	9.8	3.5	31.2
		13	—	—	—	—	—	—	—	
18	Methyl Ethyl Ketone — LiOH + CHX	2	0.1 cc	21.3	12.2	19.9	14.7	42.7	26	
		4	—	0.7	0.4	0.65	0.5	—	—	
		7	—	0.2	< 0.2	< 0.2	< 0.2	—	—	25.95
		‡ *								
		8	0.1 cc	21.4	10.1	19.6	12.1	52.8	38.3	
		9	—	1.5	0.9	1.41	1.2	40	14.9	
		11	—	0.5	0.2	—	0.3	0	0	42.83
19	Freon 22 — LiOH + CHX	3	1350 cc for 45 s	310.5	282.3	306.1	303.9	9	0	**
		6	—	No Sample	281.4	Not Available	288	—	—	
		7	—	—	—	—	—	—	—	
		‡ *								
		11	1350 cc for 45 s	381.4	380.4	381.2	389.5	0	0	
		13.5	—	361.6	356.6	360.8	357.1	0	0	**
20	Dichloromethane — LiOH + CHX	1	0.15 cc	18.4	16.0	18	16.1	13	10.5	
		5	—	6.3	6.1	6.3	6.1	3.2	2.7	22.32
		6.5	—	—	—	—	—	—	—	
		*								
		7.5	0.2 cc	41.9	36.4	41	36	13	12.2	
		11.5	—	18.8	17.8	18.6	18	5.3	3.4	42.6
		13	—	—	—	—	—	—	—	

VI. PHASE III TEST PROGRAM

The Phase III test program was identical to Phase II (Section V.A) in regard to test configuration and procedures, except that the Purafil was removed from the LiOH canister and replaced with charcoal and the LiOH canister flow-rate was changed to 51 kg/h (26 cfm). Design information was not available at the time of Phase III testing; therefore, a mass of charcoal required to fill the inner annulus (Fig. 6) was calculated. This calculated mass was 186 gm (0.4 lbm).

Detailed Phase III test results including grab sample results, calculated bed contaminant removal efficiency, and rates are given in Table 9. Removal efficiencies and rates were calculated using the equations given in Section IV.C.

Test data indicated baseline ECS removal for carbon tetrachloride, chloroform, trichloroethylene, allyl alcohol, trichloroethane, acetone, and 1-butanol. No removal was noted for methyl chloroform.

VII. CONCLUSIONS AND RECOMMENDATIONS

Based upon the test results discussed in the previous sections, the following conclusions can be drawn:

1. A significant number of trace contaminants were shown to be removed by the materials in the LiOH canister and the CHX.

2. Previous trace contaminant system designs did not account for baseline ECS contaminant removal which resulted in a very conservative design. The Spacelab baseline ECS test data from this test program was utilized by Lockheed Missiles and Space Company, Sunnyvale, California in an analysis [9] to determine supplementary contaminant removal requirements. This analysis indicated that accounting for the baseline removal resulted in a decrease in the complexity of the supplementary trace contaminant removal system design for Spacelab.

3. The test program verified that trace contaminant removal rates were very dependent on inlet concentration levels. The ideal test program would produce a curve of individual contaminant removal versus concentration level. These type data were not generated, instead average removal rates were calculated using chamber contaminant concentration decay data.

TABLE 9. PHASE III TEST RESULTS

Test No.	Contaminant and Test Configuration	Test Time (h)	Contaminant Injection	Sample Results (ppm) A Inlet LiOH	B Outlet LiOH	Inlet CHX†	C Outlet CHX	Contaminant Removal LiOH (%)	CHX (%)	mg/h
21	Carbon Tetrachloride — LiOH + CHX	2	0.1 cc	9.7	8.9	9.6	9.0	8.2	6.2	
		5.25	—	1.0	0.8	0.97	0.9	20	7.0	35.74
		↕ *								
		5.33	0.1 cc	8.3	7.6	8.2	7.4	8.4	9.7	
		8.75	—	3.3	3.2	3.29	3.2	3.0	2.7	19.35
	Carbon Tetrachloride — LiOH	0.083	0.1 cc	7.3	7.3	—	—	<1	—	
		2.75	—	0.4	0.4	—	—	<1	—	34.54
22	Chloroform — LiOH + CHX	0.083	0.1 cc	0.2	10.9	—	11.0	—	—	
		3	—	0.3	5.6	—	5.6	—	—	—
		0.083	0.1 cc	7.4	2.0	6.75	2.7	73	60	
		3	—	<1.0	<1.0	<1.0	<1.0	—	—	22.64
		↕ *								
		3.083	0.1 cc	5.8	2.4	5.39	1.4	59	74	
		6.166	—	<1.0	<1.0	<1.0	<1.0	—	—	16.05
23	Methyl Chloroform — CHX	0.083	0.1 cc	26.4	—	—	29.2	—	0	
		3.66	—	22.8	—	—	23.2	—	0	0
24	Trichloroethylene — CHX	0.083	0.1 cc	2.6	—	—	1.8	—	31	
		3	—	1.9	—	—	1.9	—	0	2.73
		0.083	0.1 cc	18.3	—	—	18.1	—	1.1	
		3	—	14.1	—	—	13.9	—	1.4	16.38
25	Allyl Alcohol — LiOH + CHX	0.083	0.1 cc	4.9	1.7	4.5	6.5	65	—	
		4	—	0.7	<0.7	<0.7	<0.7	—	—	5.69
		↕ *								
		4.083	0.1 cc	3.0	0.9	2.74	1.6	70	42	
		6	—	<0.7	<0.7	<0.7	<0.7	—	—	6.36

* Overnight Lockup
† Calculated Value

TABLE 9. (Concluded)

Test No.	Contaminant and Test Configuration	Test Time (h)	Contaminant Injection	Sample Results (ppm)				Contaminant Removal		
				A Inlet LiOH	B Outlet LiOH	Inlet CHX†	C Outlet CHX	LiOH (%)	CHX (%)	mg/h
26	1,1,2 Trichloroethane — LiOH + CHX	0.083	0.1 cc	5.9	3.8	5.65	2.7	36	52	
		4.25	—	<0.5	<0.5	<0.5	<0.5	—	—	13.73
		↕ *								
		4.33	0.1 cc	7.3	4.1	6.92	5.2	44	25	
		8.50	—	<0.5	<0.5	<0.5	<0.5	—	—	17.28
27	Acetone — LiOH	0.083	2.4 cc	100.3	57.9	—	—	73.2	—	
		3.5	—	27.2	25.2	—	—	7.3	—	107.5
		↕ *								
		3.58	2.4 cc	107.6	72.5	—	—	32.6	—	
		6.75	—	43	40.8	—	—	5.1	—	102.4
27	Acetone — CHX	0.083	2.4 cc	136.3	—	—	131.9	—	3.2	
		3.5	—	95.1	—	—	98.6	—	—	60.6
28	1-Butanol — LiOH + CHX	0.083	0.5 cc	2.1	<2.0	<2.0	<2.0	—	—	
		2.5	—	<2.0	<2.0	<2.0	<2.0	—	—	—
		↕ *								
		3.58	1.0 cc	5.5	<2.0	5.1	2.5	64	51	
		5.0	—	<2.0	—	—	—	—	—	9.21
		↕ *								
		5.083	2.0 cc	9.2	—	—	—	—	—	
		7	—	<2.0	—	—	—	—	—	
		9	—	<2.0	—	—	—	—	—	11.7

The following recommendations apply based on the conclusions noted in this section:

1. Future trace contaminant removal system designs should account for contaminant removal by the baseline ECS. This approach will result in a less complex design.

2. A more comprehensive test program should be conducted for future programs which would determine the baseline ECS individual contaminant removal for various inlet contaminant concentrations. Results of these tests would yield a curve of individual contaminant removal versus concentration level.

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APPROVAL

SPACELAB BASELINE ECS TRACE CONTAMINANT REMOVAL TEST PROGRAM

By C. D. Ray and J. B. Stanley

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

J. W. LITTLES
Chief, Life Support and Environmental Branch, Engineering Division, Structures and Propulsion Laboratory

W. E. DICKSON
Chief, Mechanical Systems Simulation Branch, Systems and Components Test Division, Test Laboratory

G. D. HOPSON
Chief, Engineering Analysis Division, Structures and Propulsion Laboratory

P. M. HUGHES
Chief, Systems and Components Division, Test Laboratory

A. A. McCOOL
Director, Structures and Propulsion Laboratory

E. H. CAGLE
Director, Test Laboratory

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